To. Mr Charles Whiteford
from his very affectionate & sincere friend
The Author

EXPERIMENTAL INQUIRIES

CONCERNING THE

LAWS OF MAGNETIC FORCES.

BY

WILLIAM SNOW HARRIS, Esq.

FROM THE

TRANSACTIONS OF THE
ROYAL SOCIETY OF EDINBURGH.

(Read April 1829.)

EDINBURGH:

PRINTED BY P. NEILL.

MDCCCXXIX.

It is expected that those AUTHORS who receive separate Copies of their Papers, will prevent them from being reprinted till one Month after the Publication of the Volume in which they are inserted.

By Order of the Council,

JOHN ROBISON, SEC. R. S. E.

EXPERIMENTAL INQUIRIES

CONCERNING THE

LAWS OF MAGNETIC FORCES.

1. In the following investigation, it has been my endeavour to elucidate some of the complicated phenomena observable in all the known operations of Magnetic Forces: The labours of so many profound inquirers in this important department of physical science, are indeed such as almost to discourage those less gifted with similar powers of research from engaging in the same pursuit; but knowledge is progressive, and the splendid researches which have displayed the highest efforts of genius serve rather to assist than to deter others in more humble endeavours to promote the advancement of science.

2. Many excellent writers have well observed, that, to arrive at a perfect knowledge of the laws of magnetic action, we should have it in our power to submit magnets and ferruginous bodies to the test of experiment, but that the combined effects which these forces exhibit have at all times rendered such experiments very difficult and precarious; so that it has been almost impossible to obtain from them simple results.

3. It may not therefore be altogether useless to describe an instrument calculated to obviate some of the difficulties which have thus impeded the efforts of experimentalists in their endeavours to investigate the laws of magnetic forces, in which, by the

application of a very simple principle, aided by an easy and delicate mechanism, I have sought a means of observing the action of one magnet on another, or that of magnetised upon unmagnetised iron or steel, so as to estimate either the final result of the compound action, or the separate forces of which such action is compounded.

4. Plate X. Fig. 1. represents an instrument which may be considered as a species of balance with equal arms. There is a light wheel of brass *abcd*, Figs. 1. & 2. about two inches diameter, whose centre *i* is placed in that of an arc MIN. This arc is the quarter part of a circle, having a radius of between six and seven inches: it is divided into 180 equal parts; 90 in the direction IN, and 90 in the direction IM; the point I being the bisection of the arc, and marked zero. There is a short steel pin which projects at *b* for about half an inch from one of the arms of the wheel, through the circumference: this pin sustains an index *b*I, Fig. 1. formed of a light straw, which being tubular, is easily placed on it, so as to fit sufficiently tight; the distant extremity of this index is cut in the manner of a common writing pen, and is carefully tapered to a fine point. From the opposite arm at *d*, a similar pin projects, on which is screwed a very small brass ball, which being adjusted either nearer to or farther from the centre, is made so nicely to counterbalance the index, that the wheel, when resting on its axis, is almost indifferent as to position, the index remaining on any part of the arc, or nearly so.

5. The axis of this wheel *abcd* is formed for a short distance at each extremity into fine cylindrical pivots, which rest upon the angles formed by four lesser or friction-wheels: these are also about two inches in diameter, are constructed in the lightest way possible, and are placed two of them before, and two behind

the frame which sustains the graduated arc; they are mounted on very delicate pivots, terminating in fine points *.

6. The five wheels just described, with the graduated arc, are sustained by a projecting frame of brass ABD; and the whole is supported by a vertical column of wood or brass DE, about fourteen inches high. The frame of brass ABD projects six inches from the column, and is united to it at D by means of a small nut and screw. The column DE is screwed, at its lower extremity, into a circular base B′, of 10 inches diameter, supported on three adjusting screws, *g*, *h*, *k*. There are two lines of silk, each three inches in length, *bcm*, *ban*, Figs. 1. & 2., which pass from the point *b* in opposite directions, over the circumference of the wheel *abcd*, and terminate in two small hooks *m*, *n*: these lines are secured close to the point *b* on each side of it, by means of a small knot, and by passing them through holes drilled in the circumference, as in Fig. 2. The circumference is slightly grooved to receive these lines, and prevent them from slipping over the edge of the wheel.

The line *bcm* sustains a small cylindrical piece of soft iron, or otherwise a small cylindrical magnet *x*, Fig. 1., which being first attached to a loop of silk †, is suspended on the hook at *m*. From the opposite hook *n* there is suspended in a similar way a cylindrical counterpoise of wood W, the lower half of which is immersed in distilled water. The water is contained in a cylindrical vessel of glass, whose interior diameter is so great that any

* The opposite extremities of the pivot-holes are faced with small portions of fine watch-spring, as at *ef*, Fig. 1. which mark the centres of the two front wheels. Thus all friction which might possibly arise from the occasional contact of the shoulder of the pivot is prevented.

† The loop is formed by a doubled piece of fine silk, inserted in a small hole drilled vertically into the centre of the upper part of the cylinder *x*, and secured there by a small peg of wood passed down into the hole between its two extremities.

change in the altitude of the water, in consequence of the immersion or emersion of a small portion of the cylinder W, does not sensibly influence the indications on the arc MIN.

7. The cylindrical counterpoise just mentioned is made of fine-grained mahogany: it must be turned very accurately, and must be perfectly free from grease or varnish of any kind, so that becoming readily wetted by the water, it moves in it with great freedom. The body of this counterpoise is from two and a half to three inches in length: its lower extremity terminates in a short stem *p*, on which is fastened a brass ferule, having a screw at its lower part, by which means a small hollow ball of brass *b′*, from three to six-tenths of an inch in diameter is attached to it, being previously so loaded as to balance the suspended body *x*, and bring the index *b*I within the range of the arc IN, when the lower half of the cylinder W is about one-half immersed in the water. The upper extremity of the counterpoise terminates also in a short stem at *o*, and in a small hemispherical cup; this cup is intended to receive the additional weight requisite to bring the index to zero; and thus, by means of some fine shot, which are very convenient for the purpose, the index may be regulated with great precision *.

8. It appears evident from the nature of this arrangement, that the gravity or weight of the body *x* being as it were destroyed

* It is requisite to have several of these cylinders of different diameters, namely, from 0.2 of an inch, to an inch, each increasing in diameter about 0.1 of an inch. They should be very accurately turned, and, before being used, should be freely wetted throughout their whole length, which is best effected by allowing them to remain for a short time immersed in water as high as the upper stem. They are suspended in their situation by means of a loop of silk, inserted in the bottom of the hemispherical cup into a small hole drilled through its centre into the stem, and secured there with a small peg of wood in the way already described in note on p. 5.

by a contrary and equal force, it may be considered as existing in free space, devoid of weight, and it will therefore remain quiescent, until some new force be applied to it; and thus the action of the force we seek to investigate will become so far evident and unimpeded by any obstacle arising from gravity, except the friction and inertia of the wheels, and the resistance of the air *, which in this case need not be taken into account.

Thus, if an attractive force cause the body x, Fig. 1., to descend, then the index bI will move forward in the direction IN, until a portion of the cylinder W drawn out of the water, ceases to displace as much of the fluid as is equivalent to the force applied; and thus we obtain a constant and known measure of the new force, within a given range, which will be more or less extended, according to the dimensions of the cylindrical counterpoise W, the intensity of the force, and the rate of its increase. In like manner, if a repulsive force act on the body x in a contrary direction to the former, then the index bI will move in the direction IM, until a new portion of the cylinder W becomes immersed in the water; and thus an equivalent to the force of repulsion is obtained in a converse way to the preceding.

9. Previously to suspending the cylindrical counterpoise just described (7.), the body x is to be put in equilibrio with an equal and similar weight x', Fig. 1*, in order to observe, if when loaded with the whole, the index is indifferent as to position on any part of the arc, or nearly so, after carefully bringing it to rest. (The weight of the silk, which is necessarily transferred from one side to the other by the motion of the wheel, being considered of no value). For this purpose, there is a small hollow cylinder of brass x', Fig. 1*, about the same dimensions as the

---

* These weights being placed under the same circumstances as the weights in the celebrated machine of Mr Atwood.—See Atwood *on Rectilinear Motion.*

cylinder x: it is closed at each end, but has a small hook screwed into the upper part, which can be occasionally removed, so as to load the interior with as much weight as shall make it exactly equal to the weight of the iron or magnet x, when weighed in an accurate balance. The machine, with the iron x, thus put in equilibrio, will be sufficiently delicate, if, when loaded with a weight of 500 grains, about one-tenth part of a grain will set it in motion.

To retain the wheel abc, Fig. 1. in its situation at the time of removing either of the suspended bodies, there is a small brass prong, Fig. 4. occasionally inserted in two holes drilled through the quadrant, so as to enclose the steel point b which carries the index: thus the wheel cannot fall either to one side or the other.

10. In order to regulate the distance at which an attractive or repulsive force may be caused to operate on the body x, there is an adjusting apparatus represented in Fig. 1. by means of which a magnetic bar H, or a horizontal plane AB, Fig. 9. (Pl. XI.), may be elevated or depressed through any required space.

It consists of a vertical screw ST, Fig. 1., eight inches in length, which passes through a corresponding nut at s, resting finally upon the metallic foot at T: this foot is secured to a circular base of a convenient size. The nut at s is fixed to a small horizontal plane of brass, sy, an inch and three quarters in length, and an inch wide: this plane is preserved in its position by the guide Sh, which also assists in supporting the circular top S; there is a brass rod of about three-tenths of an inch in diameter, and eight inches long, which passes freely through a small projecting ring at S, and is screwed beneath into the brass plane at h'; the use of this rod is to sustain the square band of brass V, through which passes the magnet H and scale my. The band V is united to the upper part of the brass-rod by a nut and screw at r, and incloses a space an inch wide, eight-tenths of an inch long, and about half an inch in depth *. The magnet and scale which pass through this opening rest in a corresponding band y below; this lower band being fixed to the brass plane. Each band has two small screws, the milled heads of which are seen projecting at V and y: these are to retain the magnet and scale firmly in their place by slight pressure. When small magnets are used, they are easily secured in their situation against the scale my, by a slight pressure of the screw V. The magnet and scale being fixed, we are enabled, by turning the head of the vertical screw at S, to raise or depress them through any required interval within the range of the screw, and so adjust the distance between the upper pole of the magnet and the lower pole of the suspended body x, with great accuracy.

11. Besides these means of adjustment, there are one or more detached bands of brass, Fig. 3., somewhat similar to the fixed bands already described, which are occasionally applied to any part of the divided scale, so as to fix a magnet, or a mass of iron, at any required distance from each other, as shewn in Figs. 5. & 12., or otherwise allow of pressure being made about the centre of the bar, as at H, Fig. 1., by which means it can be elevated on the scale if necessary. These bands also serve to sustain a magnet or a mass of iron in an horizontal position, as in Fig. 11., there being two spaces, hh, Fig. 3., through the sides.

12. When it is required to examine the force of a magnet in a vertical position, it is placed in the situation just described (10.), and then transferred immediately under the suspended body x, there being a portion of the circular base B′, Fig. 1., removed

* The spaces are sufficiently large to receive one or more magnetic bars of a convenient size, the interval, when only one is employed, being filled up by a piece of wood placed behind the scale, to keep it steady. The scale extends about three inches above the magnet, and through its whole extent below: it can therefore be raised between the magnet and wood to any further altitude required.

for this purpose, so that the adjusting apparatus rests on a base independent of that which sustains the rest of the machine; and when it is required to examine the same force, the bar being placed in an horizontal position, it is then laid on the horizontal plane before mentioned (10.), and represented in Fig. 9, the divided scale *my* being now a detached piece of wood or brass, fixed against one of the perpendicular sides of a right-angled triangle, it can thus be transferred to any part of the bar. There is a small spirit-level occasionally placed on the plane AB, in order to indicate, as nearly as possible, the horizontal position, when adjusting the distance by means of the screws S, S, Fig. 9.

13. The iron or magnet *x*, Fig. 1, and the cylindrical counterpoise W, being accurately suspended, and the index adjusted at zero, if the least impulse be communicated to either side, a long continued and delicate oscillation will take place before the index again returns to its point of rest, which it finally does at zero, thus evincing great freedom of motion.

The accuracy of the whole machine should now be finally examined, by placing successively small weights of a grain or more, according to the dimensions of the cylindrical counterpoise, first on the suspended body *x*, and afterwards in the hemispherical cup at *o*. Thus, if one grain moves the index in either direction 5 degrees, two grains should move it 10 degrees, and so on; and the motion on each side of zero should correspond.

Beside the certainty we thus obtain of the accuracy of the instrument, or the error to which it is liable, we are enabled to refer the force indicated to a known standard of weight, which is every where the same, it being only necessary to state the distance at which the force acts, and the dimensions of the body *x*, supposing it to be of soft iron of the ordinary kind. Thus, if the distance should be an inch, and the index marking 25°, we might say the magnetic bar at an inch distance exerted on our suspended iron x a force of 5 grains, supposing $5^\circ = 1$ grain; and thus the indications of such a machine, like the thermometer, become universal *.

14. Experimental inquiries concerning the laws of magnetic forces being, as already observed (2.), much embarrassed by the complicated action which such forces exhibit, we are first led to examine the absolute attractive force exerted between a magnet and a mass of iron, when placed at various distances from each other, in which case, we may consider that a permanent magnetic developement exists only in one substance; but in this inquiry, it is essential to understand clearly the laws and operation of induced magnetism, that is to say, the influence which magnetised steel exerts upon ferruginous bodies not magtic, so as to induce in them a developement of magnetic properties, such effect being the most simple case of magnetic action.

15. For this purpose, the cylindrical piece of soft iron (13. Note) was suspended from the wheel of the instrument, Fig. 1.: it weighed 123 grains. The cylindrical counterpoise W being about three-tenths of an inch diameter, which, by experiment, gave 5° of attraction, equal to one grain. A mass of soft iron, *bc*, Fig. 5., two inches in length, eight-tenths of an inch wide, and three-tenths of an inch thick, was then affixed by means of a brass band n to the divided scale; and immediately under this

* There should be several small cylinders prepared of very soft iron, for general use, being about two inches in length, and one quarter of an inch in diameter. The iron-wire of commerce is convenient for the purpose. They should be accurately turned, and great care should be observed in freeing them from any permanent polarity, which is readily done by making them red-hot in a clay tube, or in fine sand in a small crucible, so as to keep them out of contact with the air. They may be considered sufficiently free from polarity, if, when immersed in fine filings of soft iron, there is no tendency to adhesion, or polar arrangement of the filings about their extremities.

was placed a magnet *m*, nine inches long, and of the same breadth and depth as the iron above; the whole was then transferred under the suspended cylinder *x*, as in Fig. 5, it being previously ascertained that the magnet *m* might be alone approximated within two inches of the iron *x*, without any sensible effect being produced on the index. In this arrangement, therefore, the index could not become influenced, except by the magnetic developement induced in the intermediate substance *bc*; and thus, by varying the distance *cd*, and at the same time preserving the distance *ab*, by means of the screw at S, constant, it was easy to determine the law according to which the magnetic developement in the iron proceeded; the force of the magnet *m* being considered a constant quantity, but its distance from the iron a variable one.

16. For it will be readily admitted, that any polarity which the attracting masses of iron *bc* and *x* could be supposed to acquire by position might be considered as invariable and fixed throughout the experiment, and therefore could not affect the result, and must be otherwise a quantity so small in relation to the means by which the other forces were made sensible, that it could not have any assignable value, as the masses of iron *x* and *bc* would not alone evince any attractive force, so as to be sensible by the index, however near they were approximated.

17. For similar reasons, the operation of the distant polarities, as they became developed in the attracting masses of iron *x* and *bc*, could not be supposed to exert any sensible influence in complicating the result, as will also appear by considering the circumstances under which these polarities are placed. Thus, when two magnets A and B, Figs. 6, 7. &. 8. are opposed to each other at their dissimilar poles, then, in a purely theoretical sense, and according to the most evident of magnetic experiments, N attracts

s, but repels *n*; and S attracts *n*, but repels *s*; so that the final resultant is very complicated. We may, however, imagine these forces to be so circumstanced in relation to a means by which their action is evinced, and by which they are measured, that at some distance N*s*, Fig. 6. the action vanishes. Let then the line CD represent the limit at which their influence, thus estimated, ceases: in this case, the effect of the polarity of BN upon that of A*n* must be considered as having no assignable value, until some point in A*n*, Fig. 8., upon the other side of the magnetic centre A passes the limit CD. The same may be said of the influence of the polarity of BS upon that of A*s*, so long as the points in BS remain without the limit CD; that is to say, at a distance from the points in A*s* greater than N*s*. If the magnets be only hardened and magnetised about their extremities, or if they be small, and of weak intensity, then there may arise a case in which the action is so weak in every other part except the extremities, that the result is not sensibly deranged until the pole *n* actually arrives at CD, Fig. 8. There are some further considerations as to the limit CD, not necessary here, which will hereafter be given.

18. Now, in the experiment under examination, the masses of iron *x* and *cb*, Fig. 5, during the time they are operated on by induction, may be considered as two magnets whose intensities increase at each approximation of the bar *m*. It is, therefore, only necessary to determine the limit CD, Fig. 6, of their action, when the induced magnetic force is the greatest; and we immediately ascertain if any disturbance arises from the influence of the opposite polarities. This limit, in the present case, was found not to exceed an inch and a half; and it not being requisite to approximate the distant poles within that space, the result might so far be considered free from this source of error.

19. The experiment being, therefore, arranged, as before explained (15), it was observable, that, when the magnet *m* and iron *bc* were an inch apart, and the distance *ab* adjusted to two-tenths of an inch, the index moved forward to 3°; on diminishing the distance *cd* between the iron and magnet to half an inch, and again adjusting the distance *ab* to two-tenths, the index pointed to 6°; on removing the intermediate iron, the index returned to zero, thereby shewing that it was not acted on except by the magnetic developement induced in the iron *bc* *.

In the following Table is given the results of this experiment in relation to other decrements of the distance between the iron and magnet, in which D signifies the distance *cd* between the iron and magnet, and F the corresponding force induced in the iron *bc*, the distance *a b* being always adjusted to two-tenths of an inch.

TABLE I.

D	F
1.0	3.0
0.8	4.–
0.6	5.0
0.5	6.0
0.4	7.5
0.3	10.0
0.2	15.–

It may be perceived by reference to the above Table, that the magnetic developement induced in the iron, increased in an *inverse simple ratio of its distance from the magnet.*

* The distance *cd* between the iron and magnet is readily varied, either by elevating the magnet *m*, or depressing the iron *bc*, the brass bands allowing them to slide beneath with sufficient ease, but yet, at the same time, exerting a sufficient degree of pressure to retain the iron and magnet in the required position.

20. The truth of this result was in a great measure confirmed, by ascertaining the absolute weight required to overcome the attractive force induced in a mass of iron at different distances from a magnet. The requisite apparatus for such an experiment is very easy to be constructed. There is a vertical support of wood *cd*, Fig. 10, sustained at a convenient height on two or three columns *ef*, by means of a horizontal plane *d*, the columns *ef* being screwed into a circular base *s*, of a convenient size. The magnet AB, and iron *ab*, to be submitted to experiment, are secured in the required position by the moveable bands of brass before described (11), the iron passing below through the plane at *d*. There is a portion, *a* B, of the vertical support *c d*, divided into inches and tenths of an inch, to mark the relative distances by which the iron and magnet are separated. A ring of soft steel *r*, about an inch and a half in diameter, having a light brass pan S attached to it, is suspended from the point *r* by the attractive force induced in the iron *a b*; a slender rod of brass passes through this ring *r*, being supported at each extremity in the columns *ef*, in order to prevent the ring from falling an unnecessary distance when the force of the attraction is overcome by weights placed in the pan at S *.

21. A magnetic bar being selected, two feet in length, an inch and a half wide, and half an inch thick, it was placed, by means of this contrivance, at different distances from a mass of iron of the same breadth and thickness, but not exceeding three inches in length. When the magnet and iron were two inches apart, it required, as determined by various trials, between 190 and 210

---

* The point *r* consists of a very short piece of soft iron, about two-tenths of an inch in diameter. It is screwed firmly into the centre of the iron *ab*, so as to have a perfect contact, and projects vertically for about the one-tenth of an inch from its lower extremity; thus the steel ring *r* becomes always attached in the same place.

grains to separate the ring; when the distance was an inch and a half, between 250 and 280 grains overcame the contact; on diminishing the distance to an inch, between 390 and 400 grains were required to separate the ring; and on again diminishing the distance to half an inch, it sustained a little less than 800 grains. The weights and corresponding distances may be therefore expressed as in the following Table, considering the weights as a fair measure of the attractive force.

TABLE II.

D	F
4	200
3	265
2	400
1	800

The weights, therefore, are in an inverse simple ratio of the distances, or very nearly so *.

Although this mode of experimenting is not so delicate as the former, it is still sufficient to shew that the force induced in the iron was not, in any inverse ratio, greater than that of the simple distance between the iron and magnet.

22. A similar result was obtained when, instead of placing the magnet and iron in a vertical position, as in Fig. 5, they were placed horizontally, as in Fig. 9, the suspended cylinder *x* being immediately over the distant extremity *a* of the iron *a b*. In this form of the experiment, we may consider the attractive force as proceeding from that point (*a*) of the iron, immediately

* The weight of the steel ring and brass pan S, with the silk lines, was just 100 grains. It was consequently taken into the account at each trial; and the weights finally added before the contact was broken, did not exceed 10 grains at a time, these being placed carefully in the pan.

under the suspended cylinder x; for it is not difficult to shew, that, in consequence of the other forces being small, and otherwise caused to act at very small angles, the resultant cannot differ materially from that of the force $a\,x$, and thus we approximate very nearly to a simple result. Moreover, it could be at all times ascertained experimentally if any other point b, Fig. 9, exerted an influence on the index, by withdrawing the iron and magnet until a arrived at b, the induced force in the iron being the greatest. In this instance, the index was not influenced when the iron $a\,b$ was withdrawn for a very short distance from under the suspended cylinder x; so that the force of the attraction might, without any considerable error, be supposed to emanate from the point a, the magnet M being preserved at all times without the attracting limit.

23. The magnet and iron described (21) being placed horizontally, with a small moveable scale $m\,y$, to indicate the constant distance $a\,x$, as in Fig. 9; the same process was repeated as before explained (19). The results are given in the next Table, the distance $a\,x$ being constantly made equal to two-tenths of an inch.

In this Table, D signifies the distance $b\,c$, and F the corresponding forces in degrees, 5° being equal to one grain.

TABLE III.

D	F
1.0	5.5
0.8	7.0
0.6	9.0
0.5	11.0
0.4	14.0
0.3	18.0

The trifling differences observable in some of the numbers are so very small, as to leave no doubt concerning the law we have endeavoured to investigate. It will, however, be necessary to remember, that, in these experiments, we have not examined the absolute attractive force exerted between a mass of iron and a magnet, at different distances, but merely the law of the influence of a magnet upon a mass of unmagnetized iron, so as to induce in it a development of magnetic action.

24. This simple law of magnetic induction is observed to proceed uniformly from the distance at which the force first becomes measurable, until the iron and magnet are very nearly approximated, but then begins to vary. Thus, in the preceding experiments (19. 23), when the iron and magnet were approximated within the tenth of an inch, the increments in the attractive force began to diminish. It would appear from this circumstance, either that the similar and distant polarities begin in this case to exert a sensible influence in disturbing the result, or that a limit exists, approaching saturation, beyond which the inductive effect on the iron does not proceed with the same facility as before. In either case, this limit may be supposed to vary with the power of the magnet. This was made evident by employing magnets of different degrees of intensity in succession. Thus, it was observed, that, although the induced effects on a mass of iron were at first respectively proportional to the powers of the magnets, yet the increments in the attractive force acquired by approximation began to diminish at a greater or less distance from the magnet, according as the original magnetic force was of greater or less intensity.

25. The attractive force of magnets by induction at their *distant poles* is, all other things remaining the same, inversely proportional to the lengths of the iron, and, as just observed, at

given distances, proportional to the powers of the inductive* magnets; but which will be further shewn.

In the following Table is given the results of some experiments on masses of iron similar to those before employed (15, 21, 22), and whose lengths were equal multiples of each other; the masses of iron being each placed in succession at a constant distance from the inductive magnets, as in Figs. 5. and 9.

The distance *cd* between the magnets and masses of iron was made equal to three-tenths of an inch, and the distance at which the induced force operated on the suspended iron *x*, as *a b*, Fig. 5, made equal to two-tenths of an inch.

In this Table, L signifies the length of the iron, and F the corresponding force of attraction, each 5° being equal to one grain.

TABLE IV.

Position Vertical, Fig. 5.		Position Horizontal, Fig. 9.	
L	F	L	F
1.0	20	3	18
1.5	14		
2.0	10	6	9
3.0	7		

26. A curious fact here presented itself in the course of these experiments, namely, that, whether the masses of iron were acted on through their lengths, Fig. 5, or through their breadths, as in Fig. 11, still the induced force of the superior pole did not in either case materially differ; and it became further evident, that, although the magnetic bar *m*, Fig. 11, was occasionally approximated within a distance of the suspended cylinder, at which it could alone influence the index, yet the intervening mass appropriated to itself the attractive power; and thus intercept-

* I employ this term to distinguish more particularly the magnets inducing the temporary development of magnetic properties in the unmagnetised iron.

ed all the effect which the bar of itself could otherwise produce; so that the bar being, as it were, insulated by the intervening iron, the final force of attraction might be considered to depend exclusively on the iron.

27. Although the distant poles of magnets by induction evince an attractive force inversely proportional to the length of the iron; yet the pole immediately opposed to the inductive magnet would seem to possess the same force in all cases, without any relation to the length of the iron; since by substituting a small magnet *x*, Fig. 1, for the cylinder of soft iron, and placing immediately under it in succession, at a constant distance, masses of iron of different lengths, the force of attraction indicated on the arc was observed to be in each case the same. The force, therefore, induced in each mass of iron must have been alike, since the total attractive force, as will be further shewn (37), is observed to vary with the force induced in the iron; the power of the magnet remaining unchanged, and all other things remaining the same.

This result is quite consistent with the general effect observed in opposing a long mass of iron to the pole of a magnet, in which case the distant extremity of the iron does not appear, except by very delicate tests, to be at all magnetic; whilst shorter lengths, as already shewn (19, 20), exert a considerable attractive force *.

---

* It may be from this circumstance that some profound investigators of magnetic phenomena have found, that a hollow sphere of iron exerted as much effect on a compass needle as a solid mass of the same dimensions; which might be reasonably supposed to be the case, as the iron could only become magnetic by induction, in which case the force of the proximate poles would be always the same. The force which such ball or shell, however, could exert on some third mass, not previously magnetic, would probably be found to be very different.

28. As the iron *bc*, Fig. 5, receives a magnetic developement inversely proportional to its distance from the magnet *m*, we may consequently, by varying this distance, alter the relative magnetic intensity of *bc* at pleasure; and thus, by fixing a second mass of iron *de*, Fig. 12, immediately above *bc*, at a constant distance *eb*, this mass *de* can be caused to operate on the suspended cylinder *x*, by a sort of second induction; so that, by preserving the distances *nd* and *eb*, and at the same time varying the distance *ca*, we have all the conditions required for determining the law of the inductive influence, when the force of a magnet *bc*, Fig. 12, is made to vary, but its distance from the iron *de* preserved constant. The experiment being thus arranged, it was found, as might have been previously anticipated, that the second mass of iron *de* received an attractive force directly proportionate to the magnetic intensity of the mass *bc* below.

The same result was obtained when, instead of varying the magnetic force by induction, it was varied by means of magnets, whose forces were to each other in a known ratio, applied successively, at a constant distance *cd*, under the iron *bc*, Fig. 5.

The following Table contains the results of these experiments, in which F signifies the relative magnetic intensities; *f* the corresponding force of induction; the distance *dn*, Fig. 12, and *ab*, Fig. 5, at which it operated on the suspended cylinder *x*, being two-tenths of an inch; as also the distance *eb*, Fig. 12. The distance *cd*, Fig. 5, in which the induced force in *bc* was varied by magnets, being made constantly equal to half an inch, each 5° of attraction, being in both cases equal to one grain.

TABLE V

Force varied by Induction, Fig. 12.		Force varied by Magnets, Fig. 5.	
F.	*f.*	F.	*f.*
1	3	1	5
2	6	2	10
3	9	3	15

29. From these experiments, therefore, we may conclude, that the magnetic developement in masses of iron by induction is directly proportionate to the power of the inductive force, and inversely proportional to the distance, all other things remaining the same; and that the attractive forces which magnets can develope in masses of iron at a given distance, may be considered, within certain limits (24), as a fair measure of their respective intensities.

30. It will be here proper to examine the curious phenomenon of the increased force which a magnet apparently gains at one of its poles, by placing a mass of iron in contact with the opposite one; so that, in this case, it can sustain a much greater weight, and hence its power is said to be increased. This circumstance, recorded by almost every writer on magnetic attraction, may be readily explained on the generally received hypothesis of magnetic developement, which supposes in every magnet the existence of two opposite forces; the magnetic centre being a point where these forces are in a state of neutralization, whilst the intensity of the separate forces varies in some direct ratio of the distance as they recede from each other. The intensity of the magnetism thus set free, will, therefore, be the greatest somewhere near the extremities of the bar; so that, if a portion of the magnetism at one extremity becomes neutralized, the effect is more or less sensible at the other; and thus a

further magnetic developement is induced by neutralizing a portion of the opposing force.

The force thus neutralized will, from what has been stated (29), depend on the inductive force of the magnet, and its distance from the iron ; so that the increased attractive power of the magnet at its opposite pole, is still a measure of the inductive effect.

31. The fact itself (30) is very well illustrated by placing a short magnetised piece of steel *b c*, Fig. 5, to act on the suspended cylinder *x* at a constant distance ; and, after observing the attractive force ; by subsequently opposing a mass of soft iron *m* very near the inferior pole, in which case the index will be found to advance. The effect is more decided when the iron *m* is brought into contact. The law of this action is, as in the former case, directly proportionate to the power of the magnet, and inversely proportional to the distance. Thus, a small magnetised piece of hardened steel *b c*, Fig. 5, three inches long, eight-tenths of an inch wide, and three-tenths of an inch thick, being caused to act on the suspended cylinder *x* at four-tenths of an inch distance, the indicated attraction amounted to 12°. On approximating a similar mass of iron *m*, within two-tenths of an inch of its inferior pole, the index moved forward 1° ; on diminishing the distance to the one-tenth of an inch, the index moved forward another degree.

32. The effect thus produced by approximating a mass of iron toward the opposite pole of a magnet, has not any relation to the dimensions of the iron, all other things remaining the same ; thus furnishing an additional confirmation of the curious fact before mentioned (27),—that the proximate poles of magnets by induction are of equal intensity.

33. In the experiment just described (31), the increments of the attractive force of the magnet were necessarily very small, since they depended exclusively on the iron, which had no permanent magnetism, and which operated at the distant pole. In order, therefore, to allow of an increased action, and at the same time observe the immediate operation of the iron on the pole to which it was opposed, the experiment was transformed as follows. A magnetic bar *m*, Fig. 13. (Pl. XII.), being placed in a horizontal position, with one of its extremities immediately under the suspended cylinder *x*, and the number of degrees of attraction being noted at a constant distance, a mass of iron *n* was approximated toward the same extremity. In this case such portions of the free magnetism of this extremity would become neutralized as were proportional to the magnet's inductive effect, and this would be evinced by the number of degrees which the index declined. Thus we might come to determine experimentally all the particular cases hitherto considered, a method of experimenting which, although not entirely free from objection, is still useful, and sufficiently accurate to confirm the preceding results.

34. The experiment being arranged as in Fig. 13, the effect of the iron was, as in the former cases, directly proportional to the power of the magnet *m*, and inversely proportional to the distance *a b*. In the following tables are given the results actually obtained. The magnetic bars and iron employed being similar to those before described (15). In these tables, D signifies the distance *a b* between the iron and magnet, F the intensities of the magnets, and *f* the force as expressed by the number of degrees which the index declined. The distance between the suspended cylinder *x* and the magnet *m* being, in Table VI., six-tenths of an inch, and in Table VII. eight-tenths of an inch; the constant distance *a b*, at which the variable magnetic forces were applied in Table VII. being two-tenths of an inch.

TABLE VI.

Magnetic Force constant.	
D.	*f.*
0.6	3.
0.4	4.5
0.3	6.
0.2	9.

TABLE VII.

Magnetic Force variable.	
F.	*f.*
1	2
2	4
3	6
4	8

35. In these, as in the former experiments (32. 37), the effect produced on the index was quite independent of the dimensions of the iron, and was observed to be nearly the same, whether opposed to the magnet *m* through its length, as in Fig. 13, or through its breadth, as in Fig. 14, the proximate induced polarity of the iron appearing to be in each case alike. Similar results were also obtained to those before noticed (24), in employing magnets of powerful intensities; it being observable, that, at very near approximations, the effect on the index was not precisely proportional to the powers of the magnets.

36. The general results of the foregoing experiments (34) became further shewn, when the magnetic forces employed were those induced in a mass of iron, as in Fig. 15. Thus, a mass of soft iron *d a*, not exceeding three inches in length, being placed with one of its extremities immediately under the suspended cylinder *x*, a magnetic bar *bm* was opposed to its opposite extremity *a*, so as to induce in the iron a magnetic developement; the number of degrees of attraction, and the distance of the cylinder *x*, being noted, a second and similar mass of iron *cn* was then opposed to the induced pole; and thus, by making the distance *a b* always the same, and varying the distance *c d*, the magnetic developement in *d a* remained the same, whilst the distance of the opposed iron *n c* became variable; and by making distance *c d* always the same, and varying *a b*, we are enabled to

vary the magnetic developement in *d a* (19), whilst its distance from the opposed iron *n c* is constant.

The actual results are given in Tables VIII. and IX., the distance of *x* being made constantly equal to three-tenths of an inch. In Table VIII., D signifies the variable distance *c d*, and *f* the corresponding force, as expressed by the number of degrees which the index declined, the constant distance *a b* being two-tenths of an inch. In Table IX., F signifies the variable magnetic intensities produced by approximating the magnetic bar *b m*, through the respective distances 0.6, 0.3, 0.2, 0.15 of an inch, in order to obtain the relative forces 1, 2, 3, 4, (9); *f* is the force of induction as before; the constant distance *c d* being in this case also two-tenths of an inch.

TABLE VIII.

Magnetic Force by Induction constant. Distance variable.	
D.	*f*.
0.6	3.
0.4	4.5
0.3	6.
0.2	9.

TABLE IX.

Magnetic Force of Induction variable. Distance constant.	
D.	*f*.
1	3
2	6
3	9
4	12

37. Having considered some of the principal phenomena of induced magnetism, we may now investigate more particularly the force made up of the reciprocal attraction between a magnet and a mass of iron, when placed at different distances from each other. It may be observed (19), that this combined force exerted between a mass of iron *bc*, Fig. 5, in a temporary magnetic state, and the suspended body *x*, which must be considered also in a temporary magnetic state, is, at a given distance, directly proportional to the intensity of the inductive magnet *m*, and in an inverse proportion to the distance *cd*, the magnet *m* remaining unchanged. From which we may conclude, considering

the iron bc as a magnet, that the distance ab between a magnet and a mass of iron being constant, the absolute attractive force will be directly proportional to the power of the magnet bc, and consequently to the force induced in the iron x. Thus, if two magnets, whose separate forces of induction on a mass of soft iron, at a constant distance, have been previously well determined, be opposed to the suspended iron x, as in Fig. 1, then the respective attractive forces, at a constant distance, as shewn by the index, will be observed to vary in the same ratio as before; and if both the magnets be now conjoined and opposed to the suspended iron x, at the same distance, then the indicated attractive force will be the sum of the two former forces, or very near it.

38. That the absolute force of attraction exerted between a magnet and a mass of iron should vary with the power of the magnet, and consequently with the force induced in the iron, all other things remaining the same, is what might have been previously supposed; but the ratio in which this same force of attraction might be expected to vary, when the force induced in the iron x, Fig. 1, is a constant quantity, whilst its distance from a magnet H is variable, the magnetism of H being either temporary or permanent, is not so apparent; nor has such a case, as far as I am aware, been yet contemplated; beside, that the possibility of obtaining satisfactorily all the conditions of such an experiment would appear at first somewhat doubtful. The results, however, before given (19), enable us to investigate experimentally such a case. Thus, by varying the distance cd, Fig. 5, between a magnet and a mass of iron, we can, as before observed (24), within certain limits, obtain any relative magnetic intensity required; and by varying the distance ab between the temporary magnetic pole of the iron bc, and the iron x, we can preserve the force induced in x constant. Thus, if we dimi-

nish *cd* one-half, we double the force in *bc*; and if the distance *ab* was preserved, the force in *x* would become likewise doubled (29); but if, whilst we diminish *cd* one-half, we double *ab*, then (19) the force in *x* will remain as before. We may thus preserve the induced force in the iron *x* a constant quantity, whilst its distance from the inductive magnet *bc* is a variable one; and hence arrive at the reciprocal force of attraction under these conditions. The experiment being thus arranged, it was clearly shewn, that the absolute force *varied with the distance, the induced force in the iron being a constant quantity.* Thus, by diminishing *cd* one-half, so as to double the magnetic intensity of *bc*, and at the same time doubling the distance *ab*, the number of degrees marked by the index were as two to one. By decreasing *c d* to one-third, and trebling *a b*, the observed forces were as three to one; and so on.

This curious fact was not only apparent when the magnetic force was varied by induction, but was also satisfactorily shewn, when varied by magnets whose relative powers of induction were previously ascertained.

Thus, two magnetic bars being selected, whose inductive powers were as two to one, they were placed in succession immediately under the suspended iron *x*, as in Fig. 1, but in such way that their respective distances from *x* should, as in Fig. 16, be inversely proportional to their powers of induction, the stronger magnet $2m$ being placed at double the distance; hence the want of power in the weaker bar *m* was compensated by its diminished distance *ab* (19); so that the force induced in *x* was in each arrangement the same; the forces, however, marked by the index were inversely proportional to the distances *a b* and *cd**.

---

* Although this result, as disconnected with the previous investigations concerning induced magnetism, it may be readily imagined, must happen, admitting the

39. We may conclude from these investigations (37, 38), that the actual force exerted between a magnet and a mass of iron is directly proportional to the force induced in the iron, and inversely proportional to the distance, all other things being the same; and this leads us more immediately to consider the absolute attractive force of a magnet and a mass of iron, the distances between the iron and magnet, and the force induced in the iron, being both variable.

This case of magnetic attraction, which applies immediately to the general law, as determined by the celebrated COULOMBE, and likewise by many other profound inquirers, is readily investigated, by placing a magnet to act directly on the suspended cylinder of soft iron *x*, as in Fig, 1., at different distances, by which means we vary the induced force in the iron *x*, and the distance simultaneously. Thus, if we decrease the distance, Fig. 1, one-half, we double the force induced in *x* (19), whilst we diminish the distance in the ratio of 2 : 1. If we decrease the distance to one-third, we treble the force in the iron *x*, and at the same time diminish the distance in the ratio of 3 : 1, and so on: the absolute or total attractive forces will consequently, from what has been already stated (37, 38.), be respectively in the ratio of 4 : 1 and 9 : 1; and hence we obtain a final force, which is observed to vary in the inverse ratio of the squares of the distances between the attracting bodies. Thus, when a long cylindrical magnet in Fig. 1. not greatly exceeding the suspended iron *x* in diameter, was placed immediately under it, the distance being an inch, the force indicated amounted to 5°. On diminishing the distance to half an inch, the index moved forward to 20°.

---

general law of magnetic attraction about to be demonstrated, namely, that of the inverse square of the distance; yet, on examination, and as will be further shewn, it will be found to depend exclusively on the operation of induction, and that where this operation does not proceed, the law above named no longer obtains.

The following are the results of two series of experiments, in which the distances and forces were compared by decrements of the tenth of an inch, and it will be perceived, that the trifling irregularities occasionally observed in some of the numbers, are not of such importance as to leave any doubt concerning the law we have been endeavouring to determine, and are, besides, in many instances not appreciable by the instrument. In these experiments, two magnets were employed, designated by A and B, and were such as to ensure, as far as possible, accurate results, the conditions before explained (17) being fully considered: D signifies the distance between the iron and magnet, and *f* the corresponding force of attraction; the distances being adjusted by the apparatus before described (10).

TABLE X.

Showing the Attractive Force of a Magnet and Iron on each other at various distances.

A, north pole.		5° attraction = 1 grain.	B, south pole.	
D.	*f.*		D.	*f.*
1.0	4.5		1.0	6.0
0.9	5.5		0.9	7.5
0.8	7.0		0.8	9.5
0.7	9.5		0.7	13.0
0.6	13.0		0.6	17.0
0.5	18.0		0.5	24.0

40. The law observable in the preceding experiments may be generally observed by approximating the pole of any magnet toward the suspended iron *x*, whether a small cylinder of precisely the same dimensions, or otherwise a powerful magnet of any form and length. The variation in the angles at which the attractive force of the latter may be supposed to act on the suspended iron, where the opposed surface is more extensive, not having for a short distance any material influence in disturbing the uniformity

of the result. The same law may be likewise made evident, in substituting for the suspended iron x a small magnet, and approximating toward it a mass of soft iron, as in the following Table, which are the actual results obtained from an experiment so arranged.

TABLE XI.

Showing the Attractive Force, by opposing a Mass of Iron to a Magnet.

D.	*f*.
0.6	1.5
0.4	3.5
0.3	6.0
0.2	13. +

41. It has been observed (24) that the ratio of the inductive effect of a magnet on a mass of iron begins to vary when the iron and magnet are very nearly approximated. The precise point depending on the magnetic intensity; we may therefore suppose that a small mass of iron opposed to the pole of a very powerful magnet, would become magnetised, nearly to saturation, even before the magnet and iron were brought into contact, so that, for a short distance, the increments of the force induced in the iron would be so very small, that, in such case, it might be considered as constant; and hence the reciprocal attractive force would, for near approximations, no longer vary in the duplicate inverse ratio of the distances, but in an inverse ratio very near that of the distance only,—the induced force in the iron being considered constant (38); and such is found to be the case, as will be further shown (47.).

42. We have more immediately considered, in the preceding inquiries, the attractive force exerted between a magnet and a mass of magnetized iron, in which case a permanent magnetic de-

velopement is supposed to exist only in one substance: we have now to consider very similar phenomena evinced in the action of one magnet on another, in which case there is a permanent magnetic developement in both substances,—a case of magnetic action somewhat more complicated than the former, but which is still susceptible of a similar experimental examination, the inductive action being observed to proceed, whether the bodies be permanently magnetic or not, or whether opposed at their similar or dissimilar poles *. We have consequently to investigate the operation of this inductive influence when the bodies under examination have a permanent magnetic developement of greater or less extent.

43. In order to examine the inductive action of one magnet on another, a magnetised piece of steel *bc*, Fig. 5. was placed under the suspended iron *x*, and the attractive force at a given distance duly noted. A magnetic bar *m* was then placed under it; first the similar poles, and secondly the dissimilar poles, being opposed, having previously ascertained the force of the magnetized steel *bc* at each pole, and made them equal, and having also equalized the poles of the magnet *m*, and ascertained their force. The results obtained from a series of experiments thus arranged, appeared to show in a satisfactory way that the forces acquired or lost by the magnet *bc*, at its superior pole, in consequence of the inductive action, were, within certain limits, in the inverse ratio of the distance between the two magnets; after which the increments or decrements began to diminish. In the following Table, are seen the results of a series of experiments

* Although by opposing two magnets at their dissimilar poles, we in great measure destroy their permanent magnetism, yet the inductive influence by which this is effected must still be considered as a new force induced in the magnets, since it has been capable of producing a certain effect.

with different magnets, marked 1, 2, 3, 4. D signifies the distance *cd*, Fig. 5.; and *f* the corresponding force of induction, as measured by the increments in the attraction in the case of the opposite poles being opposed, and by the decrements when the similar poles were opposed.

TABLE XII.

D.	Dissimilar Poles.				Similar Poles.			
	1.	2.	3.	4.	1.	2.	3.	4.
	f.	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*
2.0	1.0	2 —	2	4	1.0	2 —	2	4
1.5	1.5	2.5	2.5+	5.5	1.5	2.5	2.5 +	5.5
1.0	2.0	3.5	4	7	2	3.5	4	7.5
0.5	3.5	6.0	7	10	3.5	4.5	5	11 —
0.3	4	7	10		4	5	6	
0.2	5	9.5	11.5		4 +	5 +	7	
0.1	8	11	14.5		4.5	5.5	7.5	

The limits within which the inductive action varied according to a uniform law, would, from these experiments, appear to depend on the magnetic intensities, and on the circumstances before observed (24.); so that the precise distance at which it becomes irregular in its action, is not the same for each magnet; and it may be further observed, that, when the inductive action operates in a contrary sense to the poles of the magnets, the decrements vary at last more rapidly than the increments, supposing in the latter case the induction to operate in the same sense. These are points of great consequence in all experimental researches concerning the reciprocal attractive or repulsive force, as exerted between two magnets.

44. Similar variations from a regular law are observable, when the force of a magnet is made to vary, the distance between the two magnets remaining the same. Thus a magnet of a double force, opposed to the inferior pole of another magnet, circum-

stanced as before explained (42), does not, at all distances, exert an inductive influence proportionate to its power on unmagnetised iron.

In the following Table are given the results of two series of experiments with magnets, whose inductive powers on unmagnetised iron were as 2 : 1 ; and it will be seen that this ratio is not the same at all distances from the magnetised steel. The magnets are denoted by A and 2 A, placed over the respective forces of induction ; D being the corresponding distance.

TABLE XIII.

D.	A.	2 A.
2.0	2	4
1.5	2.5	5
1.0	4	7.5
0.5	6	11

These experiments shew that a variety of cases may exist in which the intensities of the magnets become so circumstanced, in relation to each other, that the inductive action no longer proceeds.

45. The absolute attractive or repulsive force exerted between two magnets at various distances, will materially depend on the operation of the inductive influence, the induced forces and the distances being both variable ; for we have already seen (39.), that the absolute force exerted between a magnet and a mass of iron, varies with these quantities conjointly. The same may therefore be inferred of the absolute force exerted between two magnets ; for a very little reflection will serve to show, that, in estimating the absolute force exerted between them, it is still the same compound action which we measure (39). Thus, as already observed, when only one of the bodies B, Fig. 6. is permanently magnetic, the absolute force is directly proportional to

the force induced in A, and inversely proportional to the distance N*s* (37, 38.); and this must be still true, though A be supposed also a magnet, seeing that the inductive action still proceeds (43.); and thus the absolute force of B upon A will vary as before (39.); but A being now supposed also permanently magnetic, it exerts a similar force on B, and which will consequently vary in the same way. Therefore, the whole attractive force between A and B will still be found to vary in an inverse ratio of the square of the distance, supposing the inductive action to go on uniformly. And this will be true, whatever be the relative magnetic intensities, the only difference between this action and that exerted between a magnet and a mass of iron, arising from the circumstance, that, in the latter, there is only one primary inductive action in the operation, whilst in the other there are two.

46. In order to investigate the absolute force of attraction or repulsion, as exerted between two magnetised bodies, the distances and induced forces being both variable, it is only necessary to substitute a small magnet for the cylinder of soft iron x, Fig. 1., and observe the attractive or repulsive forces by approximating toward it either the similar or dissimilar poles of another magnet, in the way before described (39.)

We have already considered (17.) some of the circumstances likely to interfere with the accuracy of an experiment thus arranged, and we have shewn that a limit may be determined, without which the action of the other poles may be supposed of no assignable value. It remains, however, still to be considered, what subsequent change is likely to be produced in this limit *cd*, Fig. 6, 7, 8., by the inductive action of the similar or dissimilar polarities on each other. Now, it was shown (33.), that the inductive influence of dissimilar polarities lessens their free action: the approximation of the polarity N towards *s* will therefore, supposing them of an opposite kind, tend to neutralize each other's force, and thus extend the limit CD. It is therefore extremely probable, that, in some cases, the opposed polarities N and *s* may so neutralize each other's action in regard to the other polarities *n*, S, that the force may be considered as ultimately reduced to that of two insulated points. A similar result may be supposed to follow, when the polarities are of the same kind; for although the approximation of similar polarities would seem to reduce the limit CD, yet the inductive influence (43.) tends to reverse the repelling poles; and thus the forces of the distant polarities become also neutralized. The limit CD may be therefore extended in both cases, and in many instances may vanish altogether.

In the following Table are the results of a series of experiments with the attracting and repelling poles. The magnets employed are indicated by the letters *a*, *b*, *c*, *d*, *e*, their dimensions being as follows:

a, A small cylindrical magnet two inches long, 0.2 of an inch in diameter, and similar in every respect to the suspended magnet *x*.

b, Four and a half inches long, and four-tenths of an inch square.

c, Seven inches in length, and seven-tenths of an inch diameter.

d, Nine inches long, eight-tenths of an inch wide, and three-tenths thick.

e, Fourteen inches long, one inch wide, and half an inch thick.

D, signifies the distance; whilst the letters *a*, *b*, *c*, *d*, *e* are placed over the respective forces.

TABLE XIV.

D.	Dissimilar Poles.					5° of attraction equal one grain.	Similar Poles.				
	a.		*c.*	*d.*	*e.*		*a.*	*b.*	*c.*	*d.*	*e.*
4	...	...	...	...	3 +		...	...	...	...	3 +
3.5	...	...	...	...	4 +		...	...	...	...	4 +
3	...	...	...	...	6 —		...	..	...	...	6 —
2.5	...	...	...	...	8.5		...	...	...	...	8 +
2	...	...	2.5	3	13		...	...	2	2.5	13
1.8	...	...	3 +	3.5+	16.5		...	...	2.5	3 +	15 +
1.6	...	...	4	4.5+	21		...	...	3	4 +	18.5
1.5	...	...	4.5	5.5	23		...	...	4	5	20
1.4	...	...	5.5—	6 +	28		...	...	4.5	5.5	23
1.2	...	...	7	8.5	38		..	...	5.5	7	28
1.0	1.5	2	10	12	49		1.5	2	7	9	33
0.8	2 +	3 +	15	21	...		2	3	10	11	42
0.6	4	6 —	25 +	32	...		3 +	5	14	14	56
0.5	6	8	33	40	...		4	6.5	15.5	14 +	60
0.4	9	11.5	...	...	...		6	9	17	13 *	58 *
0.3	15	18	...	...	...		8	11	11 *		

47. These experimental results are quite consistent with the operations of the inductive influence before explained (43.) We immediately perceive, by referring to the attractive forces, that the law of the inverse square of the distance is manifest through all the approximations, except a few of the last, the occasional irregularities observed being very inconsiderable; so that when the magnets are very nearly approximated in relation to their respective intensities (44.), the increments in the forces begin to decline,—a circumstance of considerable importance in our endeavours to investigate the laws of magnetic attraction; for it may be supposed that the inductive influence which thus begins to vary, may at last so far vanish, even before contact, that the absolute force, at near approximations, may, in some instances, as already stated (41.), be in an inverse simple ratio of the distance, and which was observed to happen with the bars marked *d* and *e*.

* At these distances the repulsive force was superseded by attraction.

For although the cylindrical counterpoise employed in these experiments did not admit of the forces being examined at nearer approximations than those marked in the table; yet, by substituting one of large dimensions, the forces may be carried on nearly up to the point of contact, so as to be estimated in terms of the preceding progression, since the degrees of attraction may be always compared and valued in grains of absolute weight (13.)

In the following Table are the results of the experiments so continued with the magnets *d* and *e*; the counterpoise employed being one inch in diameter, 1° of attraction corresponding to 10° of the former, and being equal to two grains of absolute weight.

TABLE XV.

Dissimilar Poles.		
D.	*d.*	*e.*
0.4	6	18
0.3	8.5	24
0.2	13	36

It may be perceived in this table, that the corresponding forces, at near approximations, do not materially vary from a simple inverse ratio of the distance.

48. This deviation from the law of the inverse square of the distance, observed in all the near approximations of the magnets in Tab. 14. may happen, as before observed (24.), either in consequence of the distant polarities having passed a certain limit, or otherwise from the inductive action not going on with the same freedom at some point approaching saturation. The latter would seem to be extremely probable, for it has already been shown (33.), that when two dissimilar polarities are opposed to each other, their free action becomes more or less neutralized. In examining, therefore, the inductive action upon a mass of iron *bc*, Fig. 5. (19.), the polarity *d* would have its free action so much reduced,

that the polarity b may be considered as always without the limit of its influence. If we add, at the same time, the neutralizing effect of x upon b, then the action of b upon d may vanish altogether. With respect to the distant polarity of m, that may, when m is a very long bar, be always considered without the limit of the action. In this case, therefore, the decrements of the inductive force in bc, as already stated, would seem to be altogether independent of any disturbance arising from the action of the *similar* poles, although, in examining the reciprocal force exerted between a mass of iron and a magnet, or between two magnets, both these causes of disturbance may probably be in operation within certain limits; and they sufficiently explain the anomalous results arrived at by different philosophers in their attempts to investigate the law of the absolute force exerted between two magnets, or between a magnet and a mass of iron, when placed at different distances from each other: some asserting that it decreased in the inverse ratio of the squares, and others in that of the simple distance; whilst many concluded, that it followed no regular law whatever, but was different for different magnets.

49. The results of the experiments with the repelling poles, are equally interesting with those of the attracting, as furnishing useful illustrations of the causes which operate in deranging the uniformity of the result. The deviations, as may be anticipated from what has already been shewn (43.), are more considerable than in the former case. It will be perceived, that a few of the first approximations in each case differ very little from the law of the inverse square of the distance; but they soon become very irregular, and afterwards approximate to the inverse ratio of the distance, until, in some instances, the pole of the weaker magnet is apparently changed by the inductive influence, and the repulsive force is superseded by attraction. The most prominent feature, therefore, in these experiments with the repelling poles,

is the circumstance of the force becoming less and less, until the polarity of the weaker magnet appears to be so counteracted by induction, that the repulsion is at length superseded by attraction *. Hence, the repulsive power of one magnet, as measured by its force on the similar pole of another, will never be equal to the attractive power, as measured by its force on the same pole, except the magnets happen to be of very powerful intensities, or opposed to each other nearly at the limit of their action, when the tendency of the inductive influence begins to be felt, without the polarity of the magnets having undergone a sensible change.

50. The curious phenomena of magnetic repulsion, which follow when two similar polarities are opposed to each other, would hence seem to arise from the tendency of the inductive influence to cause a new polar arrangement, which action the established polarities resist; so that the repulsion will be more or less evident, as the magnets are of greater or less intensity, or are separated by a greater or less distance. Thus, when one of the poles of a weak magnet is opposed to the same pole of a magnet having a great intensity, the pole of the weak magnet, if the distance between them be small, is instantly reversed, and the repulsion is not apparent, but a weak attractive effect is ob-

---

* Although the polarity of the small magnet in these experiments seemed to be reversed, inasmuch as the repulsion was superseded by attraction even before contact, yet the new polarity by induction did not appear to be permanent, since the repulsion again obtained when the distance was increased. Thus, both the phenomena of attraction and repulsion ensued, merely by varying the distance in a small degree between the magnets. The forces indicated at near approximations with the repelling poles, are only given in illustration of the curious fact, that the pole of the weaker magnet becomes reversed before contact. We cannot consider them as quite accurate for any purpose of calculation, as the suspended magnet, in consequence of the great repulsive force, is thrown out of its perpendicular direction.

served to take place. If the distance be increased, the repulsion is evident; for the strong magnet operating at a greater distance, the inductive effect is diminished (19); so that it now proceeds with less energy, and only to a certain extent. If the magnets be supposed equal, then the repulsive effect will be evident at all distances, and the tendency to a new polar arrangement will never pass the limits of equal distribution in each bar, supposing the opposed poles actually in contact.

The inductive action, therefore, according as it proceeds in the same or in an opposite sense to the polar arrangement already existing in two magnets, will either tend to increase or diminish their force; an effect so well understood practically, that, to preserve the power of the magnets perfect, they are usually arranged with their dissimilar poles in contact.

51. Our observations have been hitherto exclusively directed to the action of a magnet on soft iron, or to that of one magnet on another; but it may not be improper, before concluding them, to consider the law of the magnetic distribution in an artificial magnet of a regular figure; since, in assimilating these phenomena with terrestrial magnetism, it is of great consequence to determine the law according to which the forces are developed in different points of the longitudinal magnetic axis between the centre and poles.

For this purpose, two bars were selected, regularly hardened throughout, and magnetized, the poles of each separate bar being equal, and the magnetic centre or point of indifference equally distant from either pole. The centres and poles were carefully ascertained by means of filings of soft iron, which were sifted immediately over them on a sheet of paper strained tight on a hollow frame of wood. The line which divided the magnetic curves was observed and noted, and equal successive portions were marked off on each side of it toward the poles.

The cylinder of soft iron *x*, Fig. 17, being suspended as in the former experiments, and the bars placed immediately under it in succession, the intensity of different points between the centre and poles were carefully ascertained, by moving along the magnet under examination, so as to bring these points successively under the suspended iron; and the constant distance ascertained and preserved by means of the moveable scale and the adjusting screws, as in the former experiment (23).

In this experiment, it is essential to reduce the action to the point *a* immediately under the suspended iron, a condition which, in a purely theoretical sense, is not possible to be fulfilled; inasmuch as the attractive force will be involved in the combined action of all the other points of the bar. We may, however, under the circumstances already considered (22), approximate so nearly to it, that the resultant will not differ very materially from that of the force at *a*; so that, for a long series of points, we may obtain a uniform law, as appears evident by the following Table, in which D signifies the distance from the centre in half inches, and F the corresponding forces of attraction; the constant distance of the suspended iron *x* being placed immediately after the letters AB, which denote the respective bars.

TABLE XVI.

A 3.		B 2.	
D.	F.	D.	F.
1	1	1	0.5
2	4	2	2.0
3	9	3	4 +
4	16	4	8.0
5	25		
6	36		

From these results, it would appear, that the law of the distribution varies directly as the square of the distance from the magnetic centre; and this law can always be made apparent in a bar of steel regularly hardened and magnetized throughout. The results, however, are by no means certain in bars whose temperament and texture is irregular, or which are only hardened at the extremities: in the one case the magnetism is irregularly retained, in the other it is only sensible at the poles of the bar.

52. In order to avoid the interference of the angular forces to a still greater extent, so as to have the action reduced as far as possible to that of an isolated point, the attractive force was made to operate through a small cylindrical piece of iron, about two inches long, *ab*, Fig. 18. Thus, the suspended iron *x* was preserved always without the influence of the bar. In this case, we may suppose, from what has been before shewn respecting magnets by induction, that, in consequence of the other points of the bar acting at angular distances upon the cylindrical mass of iron *ab*, the induced force arising from these points would, in certain cases, not exert a sensible influence on its distant extremity; and thus the attractive force by induction would approximate very closely to that resulting from the point *b* of the magnet in contact with the iron, which would thus, compared with the other points acting at a distance, and under different angles, be very great, whilst a fair measure would still be obtained of the magnetic intensity; for we have already seen (29), that the masses of iron under the influence of a magnet generally exhibit, at their distant extremities, an attractive force directly proportionate to the magnetic intensities, all other things remaining the same. Now, the successive points of a magnetic bar between the centre and poles, may be considered as so many distinct magnets, varying in intensity: the inductive effect on the iron in contact with them is, therefore, a fair measure of their force. In the following Table are given the results of a series of experiments thus arranged: the magnetic bar be-

ing *regularly hardened* and *magnetized*, and the centre poles ascertained as before; it was 17 inches long, 1 inch wide, and 0.2 of an inch thick; the constant distance ax at which the attractive force acted on the suspended cylinder x, was 0.2 of an inch, and the distances are expressed in inches.

TABLE XVII.*

D.	F.
1	0.5
2	2.
3	4.5
4	8.
5	12 +
6	18.
7	25. —
8	32.

53. As all the known operations of nature are generally of the most simple kind, it is not unreasonable to suppose, that whereever we find a compound law, that law may be resolved finally into two or more elementary ones. Thus, we have found, that the absolute force of attraction exerted between a magnet and a mass of iron, or between one magnet and another, and which has been found to increase in an inverse ratio of the square of the distance, is resolvable into two simple elementary actions (37, 38), one depending on the induced force in the iron, the other on its distance from the magnet. We may, therefore, sup-

* In a series of experiments of this description, where the forces are at first very inconsiderable, but afterwards increase rapidly, it becomes necessary to vary the dimensions of the cylindrical counterpoise W, Fig. 1, by which means we are enabled to examine the force in any point of the bar at a small distance; whilst the degrees being previously estimated in grains of absolute weight, the whole can be expressed as if the same counterpoise had been employed throughout the experiment, as before explained (47), a certain number of degrees with one counterpoise corresponding to a given number with the other.

pose, that the magnetic distribution in an artificial magnet, the intensity of which increases in a direct ratio of the square of the distance from the centre, is still to be resolved into two simple actions, which may possibly be discovered by a little reflection on the manner of producing magnetic disturbance in bars of steel, and the laws according to which the opposite magnetic forces operate on each other.

54. Without stopping to inquire into the nature of the cause of magnetic phenomena, we shall only assume what is, in fact, evident by the most simple experiments, that in every magnet there are two opposite forces developed, whether we suppose them to be merely different states of the same principle, or whether we imagine them to be separate and distinct agents. These forces are observed to neutralize each other when united, and to exert more or less of free action as they become separated.

Some considerations concerning this free action have been already entered upon (30); but it will be requisite here to determine the free action developed, by separating the two opposite magnetic forces; the original magnetic intensities and the distances being both variable. For this purpose, two masses of iron *bc*, *da′*, Fig. 19, 2 inches in length, 0.75 of an inch wide, and 0.3 of an inch thick, were placed under the influence of the dissimilar poles of two magnetic bars N, N′, so as to induce in them the same magnetic intensities, as measured by the attractive force on the suspended iron *x*, in the way before explained (36), by bringing the opposite polarities *c* and *d* of the induced magnets in contact, their free action would be reduced to zero; whilst, by withdrawing them from each other, we could estimate the force of the free action in either of them; 1° when the induced magnetic force was a constant quantity, and the distance *cd* variable, the distance *ab*, *a′b′* from the original magnets being the same; 2° when the distance *cd* was a constant quantity, but the induced force variable, the distances *a b*, *a′ b′* being varied (36); and 3°, when both the distances and forces were varied; that is to say, when the distance *c d*, and the distances *a b*, *a′b′* were varied simultaneously. The experiment being thus arranged, the forces set free, as expressed by the index, at the extremity *d* of one of the masses of iron, were found to vary with the distance *c d*, when the induced forces were the same, and with the induced forces when the distance *c d* was the same; and, finally, with these quantities conjointly, when they were both made variable.

55. Now, by whatever artificial method we suppose a bar of steel to be made a magnet, whether by the single or double touch, it would not be difficult to shew, that the first states of the magnetic disturbance, as measured from the magnetic centre, would be in an arithmetical progression. Thus, if we suppose a bar of steel *a b*, Fig. 20, to have been magnetized, then the forces impressed on each side of zero may at first be conceived to go on in the arithmetical progression 1, 2, 3, or 1′, 2′, 3′, &c. If we conceive these forces to be all united in the centre, their free action would be zero. Let us now suppose these opposite forces to be withdrawn through the distances 1 1′, 2 2′, 3 3′, &c. successively; then, by the preceding experiments (54), the forces set free in the points 1, 2, 3, &c. 1′, 2′, 3′, &c. would vary directly as the square of the distances from the magnetic centre, since they vary directly with the magnetic intensities, and directly with the distances.

In the few theoretical illustrations found in the preceding observations, it has been my endeavour to wander as little as possible from experimental facts. I have not the vanity to suppose that my researches are such as to defy the scrutiny of a critical examination, or that, in so difficult an inquiry, I have obtained perfection. It is only by examining nature in a great variety of ways, that we can ever hope to arrive at an accurate knowledge of her laws. I therefore submit the results which I have obtained to the scientific world as matter for candid consideration, having, at the same time, a proper sense of my own limited powers of research *.

PLYMOUTH,
July 1. 1827.

---

* It may not be improper to state, that, in the preceding inquiries, the attracting or repelling forces have been supposed to act in parallel lines. This appears to be an essential condition of this species of force; since the reciprocal influence of any two points directly opposed to each other, as $a\,b$, Fig. 21, 22, 24, must be such as to neutralize each other's action in relation to any other point more distant; the action, therefore, between the points immediately opposed to each other is exclusive, being the nearest, and consequently the forces are parallel.

It is, therefore, only when the attracting surfaces are of unequal extent, that it becomes necessary to take into the account any other force, as $c\,d$ and $e\,f$, Fig. 22, which, in a great variety of instances, are of no assignable value; but to obviate any error which can arise from this cause, it is requisite, when very powerful magnets are employed, to give the attracting extremity of the bar an armature of soft iron, as represented in Fig. 23. A, which, in diminishing from its base, terminates in a cylindrical surface exactly equal to that of the suspended body x; by which means the angular forces, as cd, ef, Fig. 22, are so intercepted and reduced, as to be of no assignable value.

When the attracting surfaces are spherical and equal, it is requisite to determine a fixed point in each opposed hemisphere, as x and y, Fig. 24, from which the sum of all the attractions would produce the same effect as if those attractions were exerted from every point of the hemispheres; so that, in varying the distances, the intervals may be estimated from these points, and not from the immediate point of contact. These points I have found by numerous experiments fall within the opposed hemispheres, at a distance equal to one-fifth of the radius of the spheres, supposing them equal.

Royal Soc. Tran Vol XI p. 278.

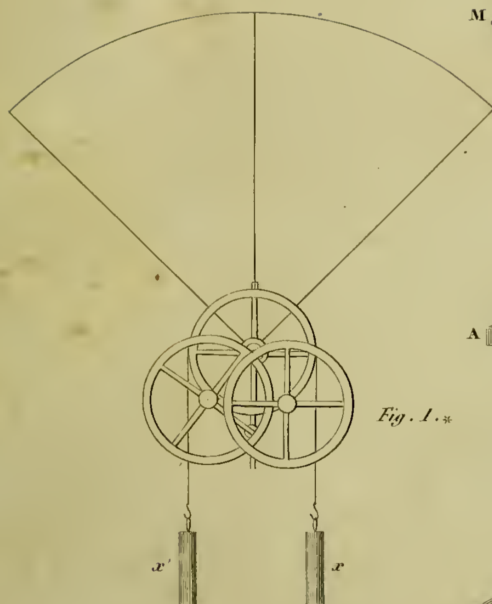


Fig. 1.*

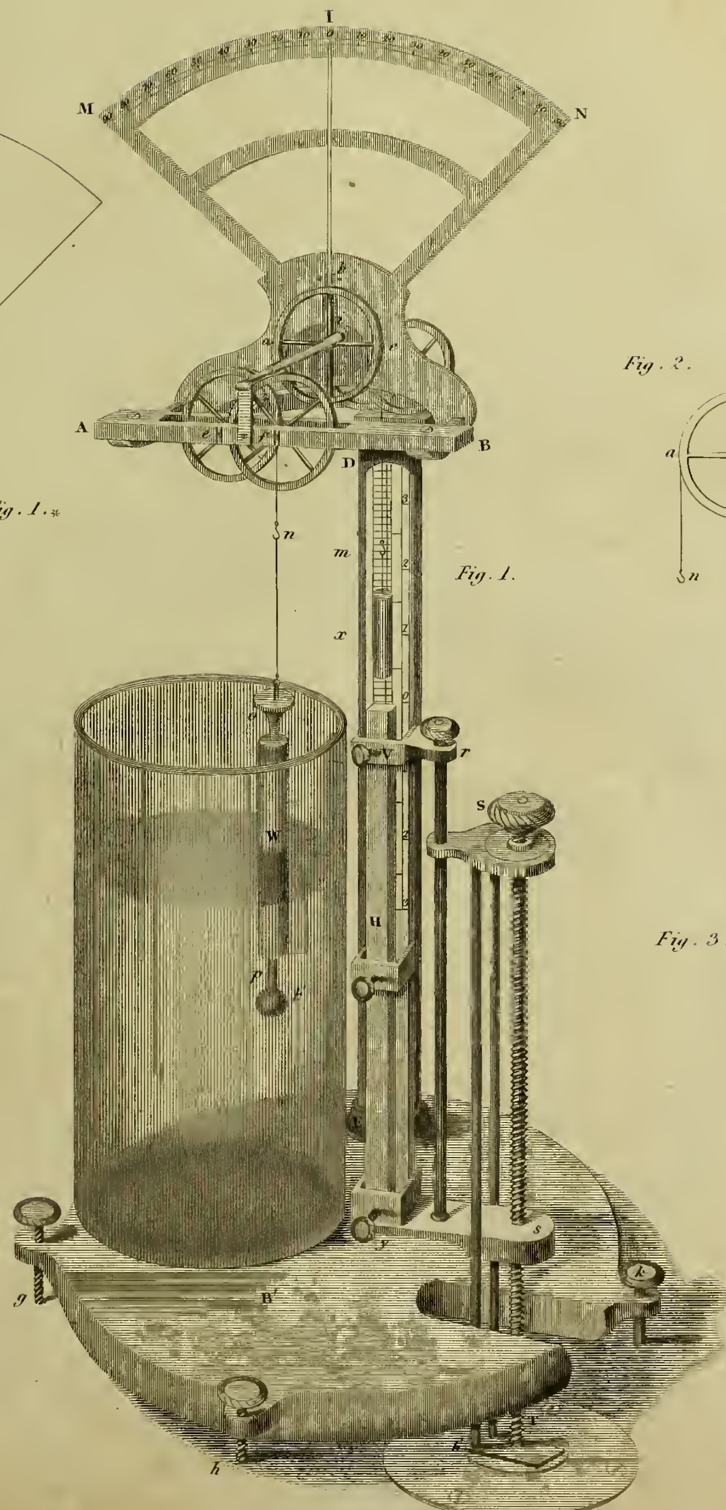


Fig. 1.

Fig. 2.

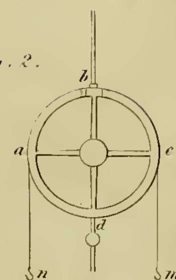


Fig. 3.

Fig. 4.

Royal Soc. Tran. Vol. XI p. 282.

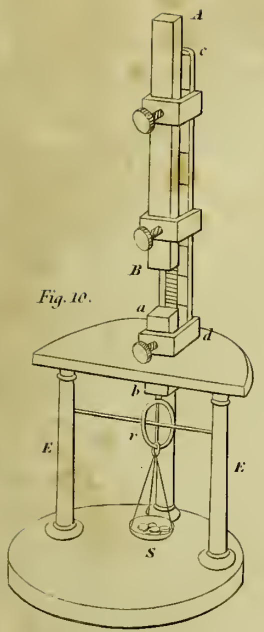
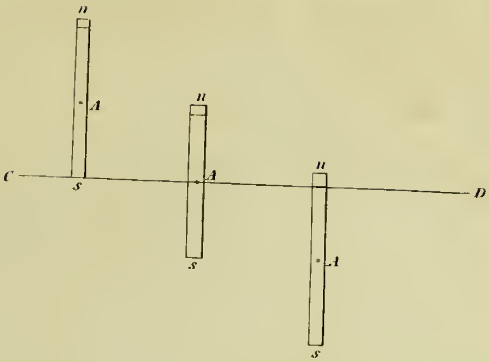


Fig. 10.



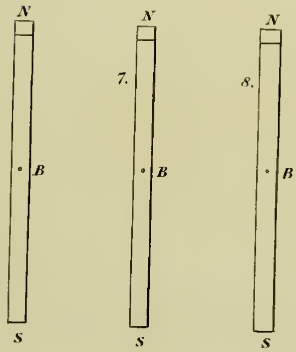


Fig. 6. 7. 8.

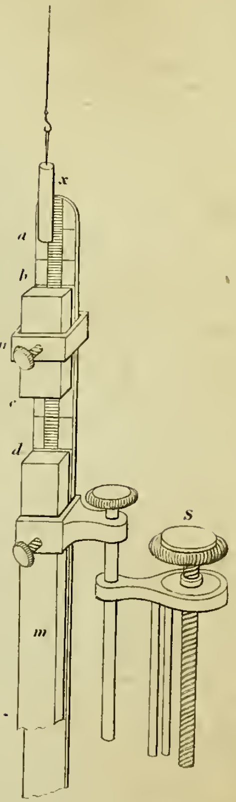


Fig. 5.

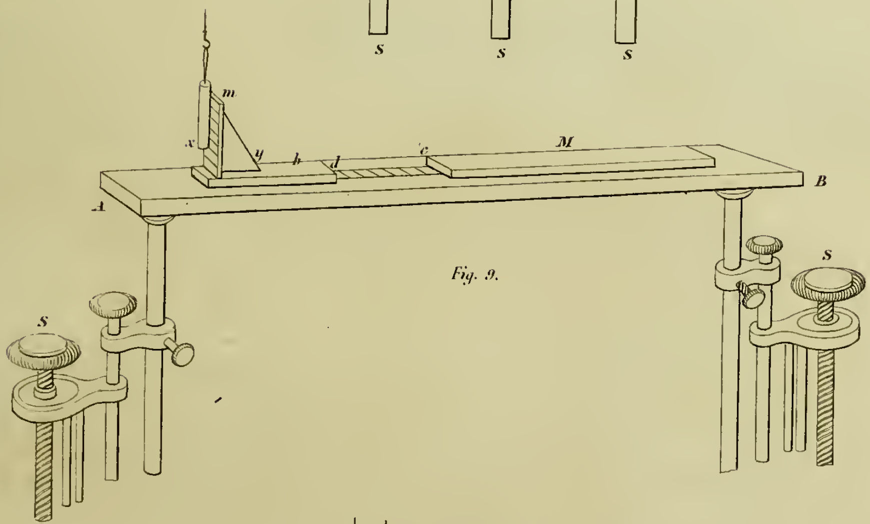


Fig. 9.

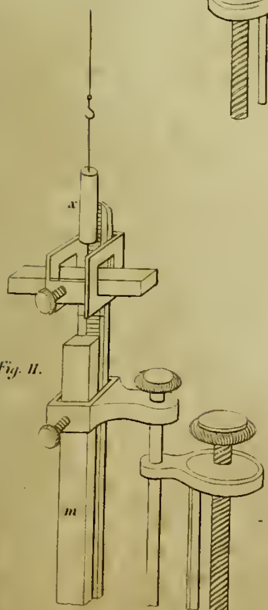
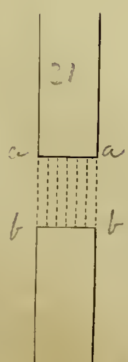
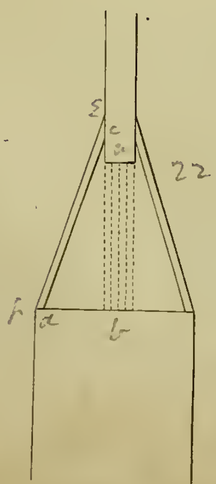
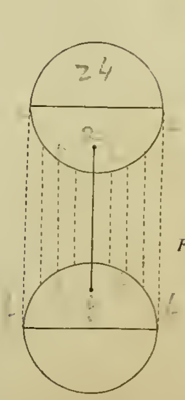


Fig. 11.







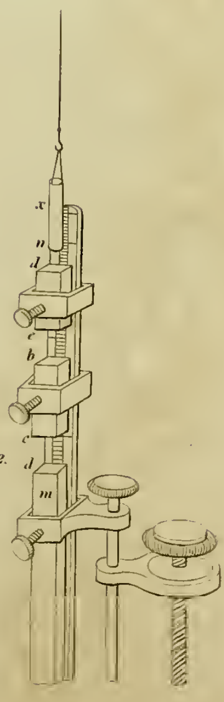


Fig. 12.

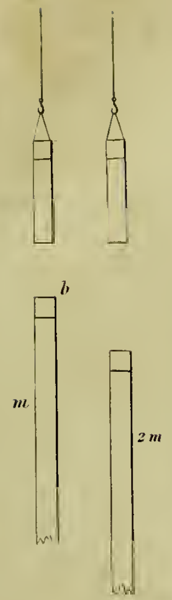


Fig. 13.

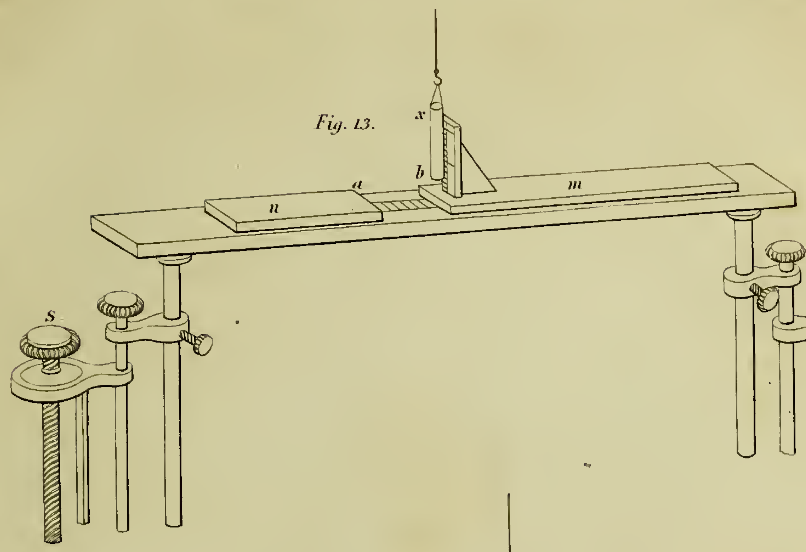
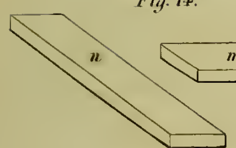


Fig. 14.



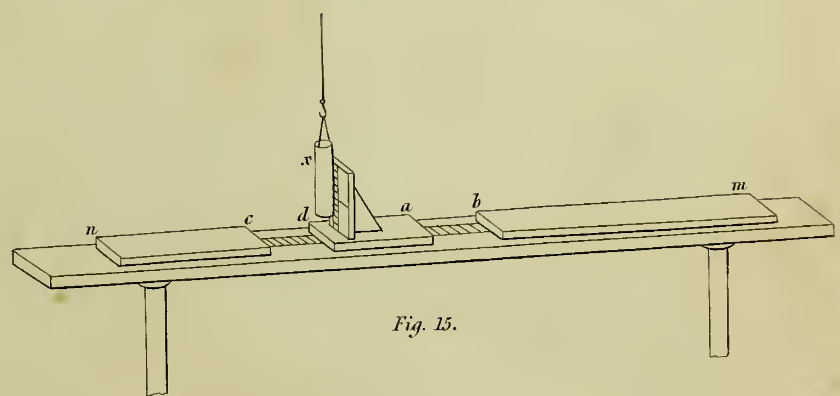
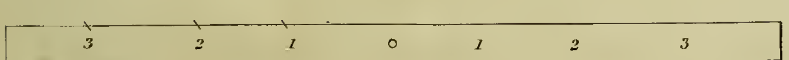


Fig. 15.

Fig. 20.



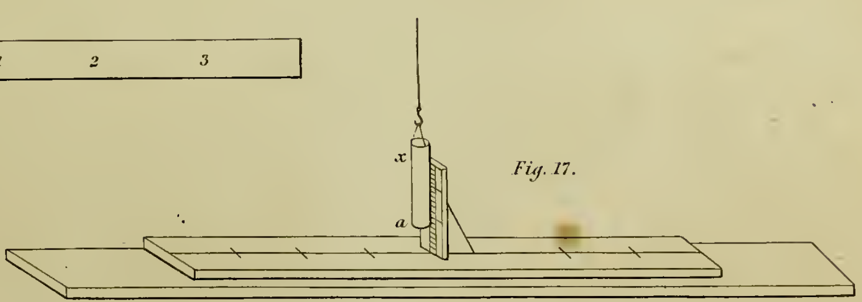


Fig. 17.

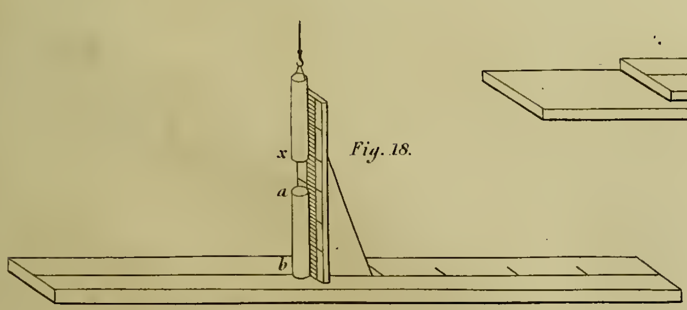


Fig. 18.

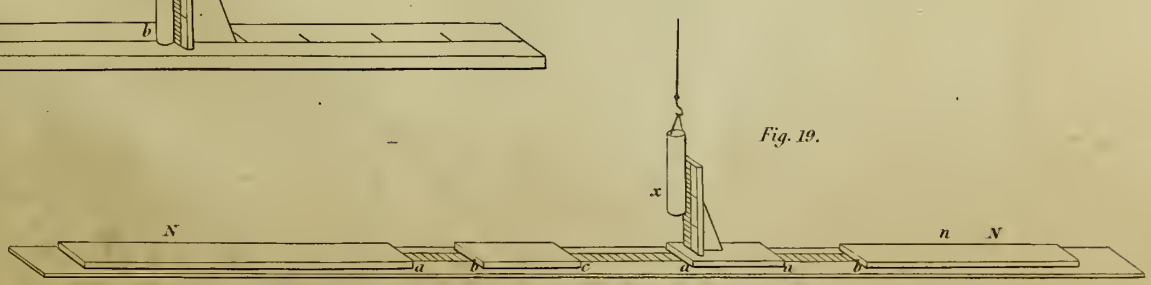


Fig. 19.

W.H. Lizars sculp^t